Operational Experience with the AMS/IB System

M. W. Johnson
Los Alamos National Laboratory

Introduction

To assist in the development of a next-generation attribute measurement system, it is valuable to review the experiences gained in the development and operation of the AMS/IB used in this demonstration. The following is an attempt to analyze the operational experience with complete candor—as the saying goes, warts and all"—regarding the difficulties encountered. It should be recognized from the outset, however, that *the pre-eminent requirement for the AMS/IB—that it securely and reliably protect classified information during a measurement—was successfully met in **100%** of the measurements on classified items where the AMS/IB was required to afford such protection.* None of the difficulties cited here should be allowed to obscure the fact that this absolutely fundamental requirement was and can be met—demonstration of which was the primary goal of the Fissile Material Transparency Technology Demonstration.

It is convenient to cast the operational experience in terms of the types of issues encountered, using the following subdivision.

- Information-barrier issues: matters associated with proper operation of the information barrier. As noted above, there were no difficulties in this regard, and consequently the information barrier will not be discussed further here.
- Physics issues: challenges posed by fundamental physics that caused measurement difficulties or reporting errors.
- Electronics issues: difficulties that arose owing to the imperfect nature of electronics and the possibility that individual modules in the measurement system might break down.
- Software issues: instances where incompletely debugged software may have complicated the analysis.
- Nuclear-material issues: cases where limitations on the available inventory of nuclear materials, both for testing the AMS/IB during the trial phase and at the demonstration, posed challenges to the system's operation.
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The accompanying viewgraphs, used during the FMTTD, summarize the issues encountered, and should be consulted in conjunction with this text.

Physics Issues

No major surprises were encountered in measurements associated with the Presence of Plutonium or Threshold Mass attributes. The measurement for the Symmetry attribute also performed as expected, given that the detector system used was not optimized for symmetry measurement. (A better, though still not fully satisfactory, means of measuring symmetry of the neutron field, as proposed by Russian scientists, would be with an isolated detector system in free space, with no scattering materials nearby.) The measurement for the Isotopics attribute was at one time posed a minor challenge by material with low ^{241}Am content, but this was resolved relatively easily, and in any event would not be an issue with more typical samples of plutonium.

Issues of some significance were identified in the Absence of Oxide and Age measurements. The problem of the origin of the 871-keV line is described elsewhere, in the "Physics Basis" and "Sources and Thresholds" presentations. As for the Age measurement, an issue was recognized, concerning the definition of "age" and the method of analysis used, that requires some explanation.

The age analysis relies upon the relative abundance of ^{241}Am and ^{237}U in the plutonium, both being daughters of ^{241}Pu. Gamma-ray spectra of "old" plutonium contain more counts from americium than from ^{237}U, owing to the growing-in of the long-lived americium, while spectra from "young" plutonium show the opposite, since the uranium has much higher specific activity. However, the relative age obtained by analyzing for ^{241}Am and ^{237}U is the age since the plutonium was *purified* (i.e., purged of americium and other contaminants) rather than the time elapsed since the plutonium was *created* (i.e., the atoms of plutonium were made via neutron capture on uranium). The time elapsed since purification is always less than or equal to the time elapsed since creation, but the time since purification can be treated as synonymous with "age" for certain applications, as has been recognized in other agreements between the United States and the Russian Federation.

The physics issue that arose during design and testing of the AMS/IB resulted from this treatment of age. The United States has no significant inventories of plutonium *created* during the last decade; accordingly, to test the Age method, it was necessary to use plutonium created in the distant past but *purified* recently. The problem with this was that, during the time between creation and purification, most of the ^{241}Pu originally present in the plutonium had decayed away, owing to its short half life of about 14 years. As a result, the amounts of ^{241}Am and ^{237}U present post-purification are very small, and the lines in the γ-ray spectrum they produce are difficult to disentangle from the strong ^{239}Pu lines with similar energies, particularly since there are complicating factors associated with differential attenuation. The consequence was that the Pu300 code for age determination performed somewhat erratically when used to analyze the "young" plutonium sample. This issue has not been completely worked out (although code modifications are helping to ameliorate it), and consequently age determination with the Pu300 code has to be viewed as the least mature of the attributes measurements demonstrated at FMTTD.

Electronics Issues

All nuclear instrumentation is prone to occasional failure through the usual means of damage to amplifiers by power surges, failure of high-voltage power supplies, etc. Previous experience regarding the reliability of individual elements of the AMS/IB was basically confirmed by the AMS/IB testing and is summarized as follows.

- Neutron tubes: high reliability, mean time between failures (MTBF) of thousands of hours.

- Electronics for neutron counting: generally high reliability (MTBF > 1000 hours), with an unexplained transient problem with a shift register, solved by replacing the suspect module.
- HPGe detectors: uneven reliability; some detectors can go for years without failing, others fail (but can be repaired) soon after fabrication. A particular preamplifier design used in some of the FMTTD HPGes proved troublesome, but need not be used in subsequent AMS instruments.
- HPGe electronics including multichannel analyzers: generally high reliability; no problems occurring in the demonstration were attributed to failure of these electronics.

When failures did occur and were diagnosed, recovery via replacement of defective modules with spares was always possible. However, one important lesson learned was that incorporation of the information barrier severely hindered the diagnostics necessary to understand why problems occurred and what modules were failing. This problem would have been even more severe had the AMS/IB not included both Open and Secure modes; diagnostics in Secure mode were essentially impossible and possibly cannot be accomplished even in principle without putting sensitive information at risk. The Open mode was very valuable in helping diagnose some of the problems that did occur and determining what element(s) of the system needed to be replaced, it being prohibitively expensive to replace the entire AMS/IB.

Software Issues

The software for plutonium presence, neutron multiplicity counting, and symmetry determination proved reliable and robust. The Pu600 software for isotopics was also generally robust, but at one point had a specific problem connected with the absence of americium (used by Pu600 for recalibration) in the "young" oxide sample, for reasons discussed above. Minor program modifications sufficed to deal with this problem. The Pu900 software had a minor problem connected with instabilities in detector gain, which however was fixed easily by increasing the width of the "window" in the spectrum within which a peak would be claimed indicative of oxide. This proved satisfactory in the demonstration, although a more satisfying solution would be to eliminate the gain instability by choosing more stable detector or electronics.

The most persistent software issues were again connected with the Age attribute and the Pu300 code, in particular with the difficulty in decomposing the close multiplets in the spectral region exploited by the code, notably in the cases where only minor contributions from the ^{241}Pu daughters were present, as discussed above. A series of generally ad hoc fixes (changing the way the fits were done, changing error checking, different assumptions regarding self-attenuation) were applied to address this difficulty, with rather mixed results. In hindsight it appears that use of a wider window in the spectrum (possibly extending all the way up to the other isotopic region near 640 keV), as is done in classical safeguards codes such as FRAM and MGA, would have met this need and could have been accomplished while maintaining the integrity and security of the information barrier. However, time constraints late in the development process prevented major overhauls of Pu300 that would have allowed us to use this approach.

As with hardware issues, diagnosis of software problems proved to be complicated by the presence of the information barrier—the more so in that the system architecture did not normally permit the archiving of data even in Open mode. Many software problems can best be addressed by using a data set and tracking it step-by-step through a code equipped with diagnostics. This approach is generally not viable with an AMS/IB-like system at least once that system has started to take data on sensitive items. System testing needs to be conducted in a way, and with a schedule, that recognizes this problem, the severity of which was insufficiently understood at the inception of the FMTTD project.

Nuclear Materials Issues

The inventory of nuclear materials available for testing the AMS/IB created its own problems in certain cases, for example the sample that had to be pressed into service as "young" material with its small size and low content of ^{241}Am and ^{237}U. A minor difficulty resulted from the uncertain geometry of cans of plutonium oxide (which can shift and settle in the can) and the resulting difficulty in interpreting symmetry information obtained with the oxide samples. Finally, the high demands on the facility where the measurements were performed reduced the number of prove-out measurements that could be done before FMTTD, a factor that must be taken into account for scheduling purposes.

Conclusion

As discussed in the viewgraphs, the ensemble of these issues led to a situation as regards system operation most easily understood by dividing it into two phases: system development, and testing of a more-or-less mature system. During system development, certain subsystems worked well almost from the beginning, while others had problems that had to be solved that took some time. (Consult the viewgraphs to identify which systems worked immediately and which needed modification.) During the testing of the mature system, nearly all subsystems (the exception being the determination of the Age attribute) functioned properly well over 90% of the time. Other than the Age measurements, failures during this phase, when they did occur, were due in one case to malfunctioning hardware (replacement of which solved the problem), and otherwise apparently due to statistical outliers in data sets with limited statistics. The project team is of differing opinions as to the existence of nonstatistical errors in the measurements (again, excluding age), but it is clear that, if systematic bias does exist in most of the attributes measurements, it affects system reliability in only a very minor way—whether *zero* effect or not being open to discussion.